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An Investigation into the Efficacy of Septic Tank Systems in Removing Organics in a Subtropical Climate

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Abstract An estimated 38 million individuals, out of a total population of around 126 million, reside in urban areas of Bangladesh. The surge in urbanization and water consumption has led to a significant rise in waterborne sanitation systems within the country. One cost-effective solution for wastewater treatment is the utilization of septic tanks, which operate as anaerobic reactors, with their efficiency being closely tied to temperature conditions. This research focuses on evaluating the organic removal capabilities of a septic tank located on the Khulna University of Engineering and Technology (KUET) campus. The results show that a septic tank's ability to remove organic matter depends on the temperature, with higher temperatures making the removal process more effective. Additionally, the Total Suspended Solids (TSS) levels were observed within a range of 110–280 mg/L, 200–1030 mg/L, 160–880 mg/L, and 190–220 mg/L for the 1st, 2nd, and 3rd chambers, respectively. The maximum recorded pH values were 7.14, 7.13, and 7.11, while the minimum pH values were 7.06, 7.05, and 7.04, corresponding to the same chambers. Furthermore, the organic removal efficiency concerning dissolved oxygen (DO), nitrate (NO_3-N), and pH levels remained within acceptable limits. These results suggest that a simple treatment unit like a septic tank can effectively render previously unacceptable and unhygienic water suitable for safe disposal and potential reuse, ultimately improving the management of septic tank wastewater.

Keywords: Septic Tank; Climate Change; Waste Organics; Organics Removal.

1 Introduction

Bangladesh, a densely populated middle-income nation in the Asia-Pacific region, faces a pressing sanitation crisis due to widespread poverty [1]–[5]. Despite efforts, the country fell short of achieving the Millennium Development Goals, with 40% of the population still lacking access to adequate sanitation as of 2015 [6]–[9]. To address this issue, septic tank systems have been implemented for the effective treatment of human waste [10]–[12]. Septic tanks serve as affordable anaerobic reactors for wastewater treatment. A standard septic tank system comprises two main components: the septic tank and a network of field lines that are placed within an absorption field [13],[14]. It's worth noting that temperature serves as a crucial environmental factor that significantly impacts the functioning of septic tank-soil absorption systems [15]–[20]. The surge in urbanization and heightened water usage in Bangladesh has given rise to a proliferation of waterborne sanitation systems, yet the management of residual waste often remains inadequately addressed in infrastructure projects [21],[22]. The uncontrolled discharge of wastewater and fecal sludge poses significant environmental and public health challenges in urban and suburban areas [23]–[27].

The COVID-19 pandemic has underscored the importance of maintaining effective septic tank wastewater treatment systems to prevent the potential spread of the virus through inadequate sanitation practices [28],[29]. Many of Bangladesh's cities and towns are situated near swamps and lakes, which local residents often use for informal aquaculture. Regrettably, these water bodies are frequently contaminated with fecal matter, compromising water quality and negatively impacting the livelihoods of vulnerable communities [30]–[33]. Moreover, pollution from domestic sources further deteriorates water quality in surface water bodies and groundwater aquifers, posing threats to both natural ecosystems and public health [22],[23].

In any given community, both liquid and solid waste

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materials, along with air emissions, are produced [25],[34]–[36]. Liquid waste, commonly referred to as wastewater, constitutes the water supply used within the community for various purposes. Any water quality adversely affected by human activities is classified as wastewater [37]–[39]. In terms of its sources, wastewater can be described as a combination of liquid or water-borne waste originating from households, institutions, commercial and industrial establishments, and may also include groundwater, surface water, and stormwater [40]–[47]. Solid waste recycling practices contribute to a reduction in the amount of non-biodegradable waste entering septic tanks, prolonging their effectiveness, and promoting more sustainable wastewater treatment [48]. In some innovative septic tank wastewater treatment systems, solid waste is efficiently processed through anaerobic digestion to produce biogas, offering both a sustainable source of energy and an eco-friendly solution for waste management [35],[49]–[52]. Essentially, wastewater comprises 99.9% water and 0.1% solids [18],[53]–[55]. Efficient management of wastewater, or the lack thereof, exerts a direct impact on the biodiversity of aquatic ecosystems, thereby disrupting the essential systems that support life [38],[56]–[59]. This disruption affects a wide range of sectors, including urban development, food production, and industry. Therefore, it is imperative to incorporate wastewater management as a fundamental component of an integrated, holistic, ecosystem-based management system that spans all three dimensions of sustainable development (social, economic, and environmental) [60]–[66]. This approach should extend beyond geographical boundaries and encompass both freshwater and marine environments. In regions with well-designed rainwater harvesting systems, the collected rainwater can be utilized to supplement septic tank wastewater treatment processes, reducing the overall strain on freshwater resources and enhancing the sustainability of the system [67].

A septic tank serves the purpose of acting as a receptacle for all wastewater originating from a residential dwelling and offers a basic level of primary treatment for that wastewater [68]–[72]. This primary treatment encompasses sedimentation, flotation, and a minor anaerobic digestion process [73],[74]. The wastewater initially enters the first chamber of the septic tank, allowing solid particles to settle while scum floats to the surface. The settled solids undergo anaerobic digestion, which reduces their volume. The liquid component flows through a partition wall into the second chamber, where further settling occurs. The excess liquid, now in a relatively clear state, drains from the outlet into the septic drain field, which may also be referred to as a leach field, drain field, or seepage field, depending on the locality [75]–[77].

To maintain the efficiency of the septic tank, periodic preventive maintenance is necessary as solids accumulate within the tank over time [78]–[85]. This maintenance involves regular pumping to eliminate these accumulated solids [83],[85]–[89]. In the United States, the responsibility for maintaining septic systems lies with homeowners, as stated by the US Environmental Protection Agency [90]. Neglecting this obligation can lead to costly repairs when solids escape from the tank, leading to blockages in the clarified liquid effluent disposal system. The World Bank emphasizes that one of the most significant challenges in the water and sanitation sector over the next two decades will be the implementation of cost-effective sewage treatment systems that allow for the selective reuse of treated effluents for agricultural and industrial purposes [91]–[95]. Maintaining high hygienic standards in sanitation systems is crucial to prevent the spread of diseases [21],[22]. Subsurface sewage disposal systems pose the primary risk of groundwater contamination and are most concerning in densely developed suburban areas and locations with minimal soil covering bedrock [96]–[99]. Proper sewage and wastewater disposal is vital to safeguard public health, prevent nuisances, and protect the environment [100],[101]. Recognizing the interconnectedness of wastewater management and water quality with various other issues, especially in the context of the water, energy, and food nexus, is gaining importance [102],[103]. Wastewater management is a key factor in ensuring future water security in a world where water scarcity is on the rise [3],[104]–[107].

The study aims to achieve the following objectives: measure the temperature variations in different chambers of the septic tank across different seasons; assess the impact of temperature on the septic tank's removal efficiency during different seasons; and compare the obtained values with the standard values using graphical representations.

2 Martial and Methods

2.1 Site selection and septic tank location

As shown in Figure 1, the research team conducting this investigation chose to focus their attention on a particular septic tank that is situated on the campus of KUET (Khulna University of Engineering and Technology). The selected septic tank could be found behind the Teachers Dormitory, which was more specifically referred to as Block-A.

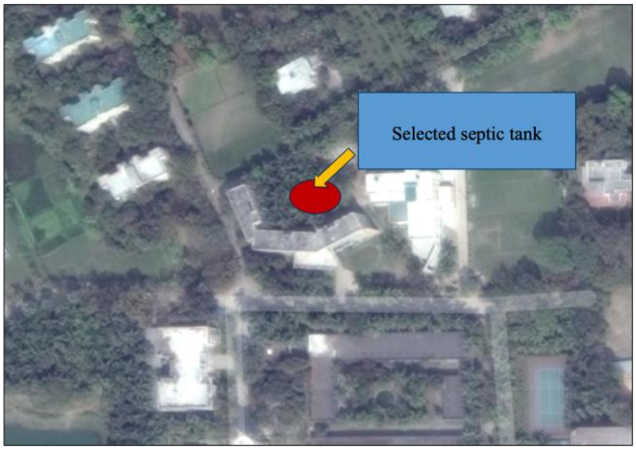

Fig. 1 Location of the selected septic tank at KUET campus

Due to the availability of a significant volume of domestic wastewater that originated from the residential units that were located in close proximity to the septic tank in question, it was determined to be an appropriate location for the research [108],[109]. Figure 2 provides a visual representation of the three separate chambers that make up the septic tank that is the subject of this investigation. Within the context of the larger system, each of these chambers serves a distinct purpose that contributes to the overall treatment and containment of the wastewater that is being processed.

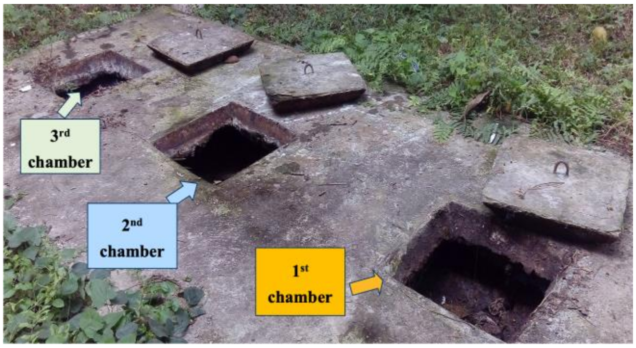

Fig. 2 The studied septic tank at KUET campus with three respective chambers.

2.2 Operation conditions

The critical step in anaerobic digestion typically involves the conversion of volatile acids into methane [110]. This conversion process is carried out by methane-forming bacteria, which yield minimal energy from the breakdown of volatile acids [110],[111]. The majority of the energy released during this process is harnessed for the production of methane. Methane-forming bacteria are strict anaerobes and display high sensitivity to alterations in factors like alkalinity, pH, and temperature [112]. Therefore, it is imperative to continually monitor and sustain optimal conditions within the digester to ensure their effective operation. In addition to alkalinity, pH, and temperature, there are various other operational parameters that should also be regularly observed and maintained within the ideal ranges to support the proper activity of methane-forming bacteria. This comprehensive monitoring and control of conditions are pivotal for the successful execution of anaerobic digestion processes. The operation conditions of the digestors are given in table 1.

Table 1 Operational conditions required for the acceptable activity of methane-forming bacteria and subsequent methane production

Parameters	Operation Conditions	Marginal
Alkalinity, mg/L as $CaCO_3$	2000	1000-1500
Gas Composition Methane, % volume	67	60-65& 70-75
Carbon dioxide, % volume	32	25-30 & 35-40
Hydraulic retention time, days	13	7-10 & 15-30
pH	7.1	6.6-6.8 & 7.2-7.6
Temperature, Mesophillic	33°C	20-30° & 35-40°C
Temperature, Thermophillic	55°C	40-50° & 57-60°C
Volatile acids, mg/L as acetic acid	**400**	500-2000

2.3 Septage characteristics

Septage refers to the mixture of liquid and solid materials that are extracted from various primary treatment sources such as septic tanks or cesspools [113]. This composite substance is formed through the decomposition of organic matter and the settling of solids within the confines of the septic tank [113]. Septage is typically removed from septic tanks through a pumping process and then transported to dedicated treatment facilities for further processing and eventual disposal [114],[115]. It is of utmost importance to effectively manage septage to prevent the contamination of groundwater and surface water sources, as well as to maintain the safe and efficient functioning of onsite sewage treatment systems. In septic tanks, scum accumulates at the surface while sludge settles at the bottom, together constituting a significant portion of the total tank volume, usually ranging from 20% to 50% when pumped out [76],[116]. Table 2 presents the septage characteristics of the septic tank.

Table 2 Septage characteristics of the septic tank

Total Suspended Solids (TSS)	15200 mg/L
Biochemical Oxygen Demand	4820 mg/L
Chemical Oxygen Demand	32500 mg/L
Total Nitrogen as N (TN)	548 mg/L
Total Phosphorus as P (TP)	230 mg/L
Oil and Grease	4500 mg/L

2.4 Wastewater collection from the septic tank

The wastewater for this research was collected with great attention to detail from two separate chambers situated within the septic tank, excluding the first chamber which had accumulated a substantial amount of sludge. To safeguard the integrity of the gathered samples, containers made of high-density polyethylene (HDPE) plastic were employed. Following that, the samples were meticulously preserved for a duration of two days in a refrigerated setting maintaining a regulated temperature of 4 ºC. This step was taken to safeguard their state before proceeding with subsequent analyses. To ensure experimental assessments were conducted with precision and consistency, the samples were subsequently allowed to equilibrate to room temperature. Figure 3 depicts the wastewater collection from the septic tank.

Fig. 3 The left side picture shows a 1st chamber of the septic tank, and the middle picture shows the collection of wastewaters from the 2nd chamber. Moreover, right side picture shows the sample of wastewater that was collected from the chamber of the septic tank

In general, a traditional septic tank comprises four essential components. To begin with, the Soak well functions as the primary entry point for the wastewater, enabling the process of solids separation from the liquid constituent. Following this, we are introduced to the initial chamber, where the process of solid-liquid separation commences. The subsequent step is for the wastewater to be further degraded and treated in the second chamber. The treatment process is concluded in the third chamber, which guarantees that the effluent discharged from the septic tank has undergone adequate treatment to be safe for consumption.

2.5 Sample analysis

The collected samples were subjected to analysis for pH, Total Suspended Solid (TSS), Dissolved Oxygen (DO), Nitrate (NO_3^-), and Electrical Conductivity (EC). The pH of the pollutant was determined using a pH meter (HACH, Model No. Sension 156). The DO meter utilized for measuring dissolved oxygen (DO) was the Hach HQ 2200. The HACH DR 2700 spectrophotometer was utilized for the measurement of nitrate levels. The HACH HQ 2100 instrument was utilized to quantify the electrical conductivity of the specimens. Gravimetric method was used for TSS measurement.

3 Results and discussions

A number of different tests were carried out in order to determine the characteristics of the wastewater that was collected from the septic tank. The outcomes of these tests are summarized in Table 3 and 4, which can be found here. These tests examined the wastewater for a variety of different parameters.

Table 3 Different Water Quality Parameters of Wastewater (2nd chamber) of the Septic Tank at KUET campus

			2nd chamber		
Date	**Temp (°C)**	**pH**	**DO (mg/L)**	**TSS (mg/L)**	**NO_3^-N (mg/L)**
26.12.20	18	-	-	280	-
05.02.21	21	7.05	1.18	1030	1.4
04.03.21	22	7.06	1.29	880	2
11.04.21	25.5	7.09	3.17	220	2.37
29.04.21	26	7.14	1.37	160	3.7
08.05.21	25.5	7.11	3.88	210	6.1

Table 4 Different Water Quality Parameters of Wastewater (3nd chamber) of the Septic Tank at KUET campus

			3rd chamber		
Date	**Temp (°C)**	**pH**	**DO (mg/L)**	**TSS (mg/L)**	**NO_3^-N (mg/L)**
26.12.20	18	-	-	110	-
05.02.21	21.5	7.04	0.45	200	0.8
04.03.21	22	7.05	1.67	160	1.6
11.04.21	25.5	7.06	3.92	190	2.67
29.04.21	25	7.13	2.17	120	2
08.05.21	26	7.03	4.57	180	2.9

The samples were gathered in a variety of months spread out over the course of the year. When looking at the data in the table, it is clear that the test results become increasingly variable as the temperature rises. This is something that can be observed. When compared to the third chamber, the TSS in the second chamber displays significantly higher values. The nitrate levels of four out of five samples in the second chamber were found to be higher than those in chamber 3. The recognition of the substantial reduction in nitrate levels is acknowledged.

3.1 pH

The pH of water is determined by taking the negative value of the common logarithm of the concentration of H+ ions [117]. The pH of natural water is 7.0. The pH scale is commonly depicted as encompassing a range from 0 to 14. The pH level typically influences the overall acidity or alkalinity of a substance [118],[119]. The acceptable range for pH in potable water typically falls between 6.5 and 8.5. The acceptable pH range for water suitable for irrigation purposes typically falls between 6 and 9. The variability in the pH level of effluent has the potential to impact the kinetics of biological reactions and the viability of diverse microorganisms. The variation of the pH values with temperature is shown in figure 4. The initial pH of the wastewater prior to filtration was measured to be 7.62. The pH values observed in the study exhibited a maximum range of 7.14, 7.13, and 7.11, while the minimum range of pH was observed to be 7.06, 7.05, and 7.04.

3.2 Dissolved oxygen (DO)

The graphical representation in Figure 4 illustrates the variation of Dissolved Oxygen (DO) with temperature. It is noteworthy that the highest DO levels were predominantly observed in the 3rd chamber, indicating a notable presence of oxygen in this particular section. However, it is worth mentioning that there was an exception, where one sample exhibited higher DO levels in the 1st chamber. The highest recorded DO value reached an impressive 4.57 mg/L, while the lowest observed DO level was 0.45 mg/L in the 3rd chamber. These DO values play a crucial role in assessing water quality as they serve as excellent indicators. It's important to note that the solubility of oxygen in wastewater is generally lower than that in clean water, making DO analysis a vital component of water pollution control and wastewater management. The significance of monitoring DO levels lies in its direct impact on aquatic ecosystems [120]. DO is a critical factor influencing various biochemical processes and metabolic activities of microorganisms, and its effects have been well-documented. The presence of adequate DO is essential for sustaining a diverse range of aquatic life forms, and the impact of water discharge into aquatic bodies is significantly determined by the oxygen balance within the system [121]. It's worth noting that the standard DO range typically falls between 4.5 and 8 mg/L, providing a benchmark for evaluating the water's oxygen content and, consequently, its overall health and suitability for various forms of life.

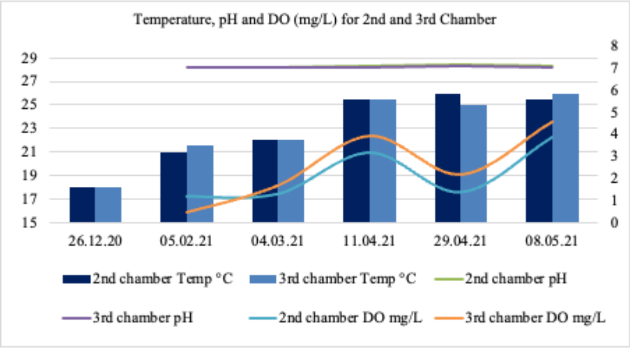

Fig. 4 The variation of pH and DO with Temperature. From the

graph it can be said that with the increment of temperature, the values of pH and DO are also increasing and it is different for the two chambers (2nd and 3rd)

3.3 Nitrate nitrogen (NO_3-N)

In the analyzed wastewater samples, the nitrate concentration was found to be relatively low, well within the standard value of 10 mg/L. Notably, there was a consistent trend where nitrate values in the 3rd chamber were observed to be higher than those in the 2nd chamber for most of the samples. To provide a comprehensive view of the nitrate content with respect to temperature variations, Figure 5 illustrates the relationship between nitrate levels and temperature. Intriguingly, it was observed that as the temperature increased, the values of NO_3-N exhibited an upward trend in the 2nd chamber. However, this pattern did not hold true for the 3rd chamber, where the values of NO_3-N did not show a consistent increase with rising temperatures. Additionally, it's noteworthy that NO_3-N values varied for the 3rd chamber at different temperature conditions.

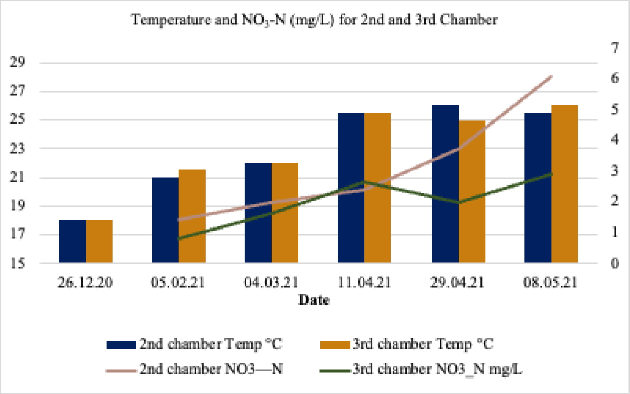

Fig. 5 The variation of NO_3-N with Temperature

The terminology "nitrate nitrogen" is used to specifically denote the nitrogen that is chemically bound within the nitrate ion. This specific nomenclature is employed to distinguish nitrate nitrogen from other forms of nitrogen, such as ammonia nitrogen or nitrite nitrogen. The analysis of nitrate nitrogen was conducted using the Hach DR2700 machine, with Nitraver 5 serving as the designated Nitrate reagent. This specialized testing equipment and reagent play a crucial role in accurately assessing nitrate nitrogen levels within the samples, providing valuable insights into the quality and composition of the wastewater under examination.

3.4 Total suspended solid (TSS)

Total Suspended Solids (TSS) is a critical water quality parameter that represents the dry weight of particles captured by a filter and is commonly used to evaluate the quality of wastewater [122]. In typical residential septic tank effluent, one can expect to find approximately 80 mg/L of TSS, a substantial portion of which comprises slowly biodegradable particles. However, the experimental findings in this study revealed an interesting relationship between TSS and temperature. It was observed that TSS levels increased as the temperature rose, and notably, the 2nd chamber consistently contained higher TSS concentrations compared to the 3rd chamber. To provide a more comprehensive perspective on this relationship, Figure 6 visually represents the variation of TSS in correlation with temperature. This graphical representation clearly indicates a direct connection between increasing temperature and higher TSS levels, with the 2nd chamber consistently exhibiting greater TSS values than the 3rd chamber.

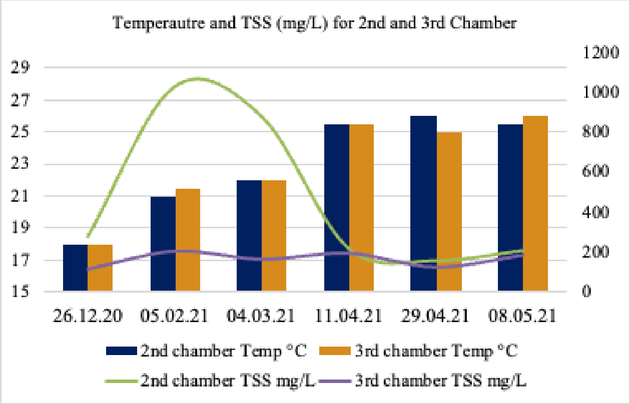

Fig. 6 Variation of TSS with the changes of temperature of different chamber

It is worth noting that the study revealed some nuances in this pattern. In the 2nd chamber, TSS levels significantly increased with rising temperatures during the initial three sampling periods, only to experience a rapid decrease afterward. In contrast, the 3rd chamber exhibited more fluctuation in TSS concentrations as the temperature increased. These intriguing findings shed light on the intricate dynamics of TSS within the septic tank system and offer valuable insights into its behavior under varying temperature conditions.

3.5 Electric conductivity (EC)

In the course of our study, we observed substantial variations in Electrical Conductivity (EC) values between the samples obtained from the 2nd chamber and the 3rd chamber of the septic tank. The EC values for the 2nd chamber were consistently higher, with measurements of 10200, 9800, 9400, 10050, and 9500 mS/cm. In stark contrast, the 3rd chamber exhibited significantly lower EC values, with measurements of 2300, 1200, 897, 1140, and 1150 mS/cm, respectively. This remarkable contrast in EC values between the two chambers is indicative of the septic tank's efficiency in the treatment process. The disparity in EC values underscores the dynamic nature of the septic tank's functionality. While the 2nd chamber seems to exhibit a higher electrical conductivity, it is vital to recognize that this may be attributed to the presence of various solutes and dissolved ions within the wastewater. As the wastewater undergoes treatment and moves through the septic tank's chambers, these solutes and ions are either transformed or removed, which could explain the noticeable drop in EC values in the 3rd chamber. These findings emphasize the capacity of the septic tank to effectively alter the composition of the wastewater as it progresses through its chambers. It also highlights the significance of EC as an indicator of the treatment efficiency, offering valuable insights into the changes that occur during the treatment process and how these changes affect the overall quality and composition of the effluent [123]. Understanding these dynamics is pivotal in assessing the septic tank's performance and its role in ensuring the safe and responsible disposal of wastewater.

4 Conclusion

This study has yielded several significant findings in relation to the wastewater characteristics of the septic tank. These findings are summarized as follows: the examination of pH levels revealed variations, with the maximum recorded pH values spanning 7.14, 7.13, and 7.11, while the minimum pH levels were registered at 7.06, 7.05, and 7.09 for both of the selected chambers. In light of the results, it is evident that the 2nd chamber consistently exhibited higher Total Suspended Solids (TSS) removal efficiency when compared to the 3rd chamber, particularly in response to temperature variations. Lastly, the investigation highlighted a noteworthy trend in the organic removal efficiency of the septic tank, demonstrating a direct correlation with rising temperatures. Specifically, the organic removal efficiency showcased higher values during the summer season as opposed to the winter season. These findings collectively shed light on the dynamic nature of wastewater characteristics within septic tank systems, offering valuable insights into their behavior under varying environmental conditions.

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